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SUMMARY

This report contains a description of a new spinning-test arrangement wherein the otherwise customary rotation of the model about a fixed axis is abandoned in favor of a corresponding rotation of the air stream. The advantage of this method lies in the fact that the model is at rest while the spin is recorded. In this manner it is possible to secure systematic results with little loss of time while employing normal 3- or 6-component wind-tunnel balances. The troublesome equalization of the mass forces is eliminated and the flow phenomena are accessible to direct observation.

I. INTRODUCTION

Model measurements on the spinning characteristics of airplanes are far less numerous than for example, the 6-component or even the 3-component measurements of normal flight conditions. The reasons for this are: first, that measurements on a spinning model are much more difficult to effect than normal measurements; secondly, that the execution of the tests up to a tangible result and the evaluation as a result of the great number of variable factors is exceedingly time-consuming.

Up to the present two methods of testing the spinning characteristics of airplanes in the wind tunnel have been in use:

1. Observation of the free-spinning model,

2. Measurement on the pivotally mounted model.

*"Eine neue Trudelmesseinrichtung." Luftfahrtforschung, vol. 14, no. 10, October 12, 1937, pp. 475-479.

With the first method (reference 1) a dynamically similar model is made to spin in a vertical wind tunnel, the air blast being upward. Regulating the air speed to equalize the momentary sinking speed of the model makes the model spin practically in one spot and its path and position can be established by camera or by direct observation. In this way it also is possible to check the effectiveness of ailerons, elevators, or other control devices, whereby the desired control deflections are released at the given time period through an installed timing gear, and the changes in flight position or path are noted. This method promises the quickest decision of the spinning tendencies of any new design.

The drawbacks of this method are: it is extremely difficult and consequently very expensive to construct dynamically similar models, i.e., models copying the mass distribution of the original. Aside from that, the results achieved in free-spinning tests are largely qualitative. The magnitude of the resultant forces and moments cannot be obtained satisfactorily but for steady conditions. The force distribution in nonstationary conditions demands double differentiation of the path curve, a method known to be little reliable. Moreover, the dimensions of the jet being limited, the pieces of the path curve available are always short. In fact, only the recovery from the spin can be copied in the spinning tunnel; the investigation of the entry with its ensuing forces and moments as well as their effect on the forming spinning position cannot be effected by free-spinning test in the tunnel.

In the second method, the model rotates about a fixed axis, preferably coincident with the axis of the jet. The problem then is to measure the six air-force components due to the rotation for each adjustable wing position before the test. Two of these components, drag and moment, about the jet axis are readily obtainable; but the rest is difficult to record and requires a very accurate mass equalization of the model. For this reason the axis of rotation is usually placed through the center of gravity, i.e., the radius of spin is made to equal zero (reference 2). This omission is relatively unimportant. But, if the measurements on the model are to include nonstationary processes, then a narrowly defined dynamic similitude is also necessary here. The ellipsoids of inertia must have equal axes ratio and equal position. Since in nearly all cases, it is necessary to stop the air stream for each change in wing position, it is obvious that a complete model measurement by this method requires an unusual outlay of time and labor.

II. THE ROTATING JET AS SIMPLIFYING MEANS OF SPIN RECORDING AND ITS FUNDAMENTAL DEFECTS

Substantial simplifications may be secured if the model is mounted stationary and the air stream is given all the necessary relative speeds. Then the spinning can be recorded on the normal 6-component balance, with the same models and mounting in conjunction with the determination of the polars without mass balance of the model and for all six components simultaneously. Moreover, the rotating jet affords an excellent means of observing the flow phenomena on the model and allows in simplest manner pressure-distribution measurements during spinning, a problem the solution of which heretofore on the rotating model had involved enormous practical difficulties.

Now, the rotating jet is from the very beginning afflicted with a number of theoretically substantiated defects. In a real spin the airplane rotates about an ideal axis in relatively quiet air. The static pressure of the free air stream is accordingly constant and the boundary-layer masses entrained by the wings are subject to the outwardly acting centrifugal forces.

The conditions are exactly reversed if the model is fixed and the jet rotates. Then the static pressure of the free air stream rises outwardly and the boundary-layer masses instead of being subject to centrifugal force are drawn inward by the negative pressure in the jet core.

These differences produce no perceptible discrepancies in the test data, as shown later on. In fact, if the boundary-layer fling-off through the centrifugal forces had a noticeable effect, this phenomenon would render the fairly satisfactory mathematical analogy between airplane wing and propeller blade impossible (reference 3).

Aside from an eventual influence on the boundary layer, the radially variable pressure may also exert forces on the model. Those must be ascertained mathematically. In the normal case, the tip speed of the wing tips is equal to half the sinking speed, and the static pressure difference between axis and wing tip then reaches one-fourth the dynamic pressure at the wing tips. If the axis of rotation lies in the plane of symmetry of the airplane, as is always the case with great approximation, the force effects of the variable static pressure on the wings should practically cancel.

The effect on fuselage and tail depends on the angle of attack of the model. Take the most unfavorable case of fuselage setting of 90°, for example. Then the effect on a fusiform body of 5 cm diameter, i.e., 19.6 cm^2 (maximum) section is a centripetal air force of 12.35 g at the 20 m/s air speed commonly used for a time in the 1.2 m wind tunnel of the D.V.L. for such measurements. The remainicr of the air forces are of other orders of magnitude; the drag, for example, is approximately 2.5 kg. Thus the error is practically always negligible, or at least, less in any case than conceded heretofore to the measuring accuracy because of the difficulty of the measurements on the rotating model.

Another potential source of error is the following: rotating a complete airplane model, for example, on its longitudinal axis in a quiescent stream, the fuselage pushes the stream filaments outward. The relative speed of the air with respect to the fuselage surface caused by the rotation of the fuselage is not affected through it in the ideal case of frictionless flow.

When the model is fixed and the stream is rotated the conditions are otherwise. The fuselage displaces a stream here also. But the air maintains its old peripheral speed, that is, its rate of rotation is too small corresponding to the increased radius relative to the fuselage surface. The result is that at the wing root the amount c arc tan U/v, by which the effective angle of attack exceeds or falls below the mean angle of attack, becomes too small. This error is small for the rolling moments in view of the short distance from the jet axis, but not, for example, when ascertaining the flow pattern on the spinning airplane, where in extreme cases the flow at the wing roots may become seaparated too late. Even so, the error is always detectable in magnitude and direction and can, if necessary, be allowed for.

III. DESCRIPTION OF SPIN-MEASURING ARRANGEMENT

To realize the desired object the jet must, besides its uniform axial speed, be given a rotation with constant angular velocity. This problem was attacked in the following manner:

Every resistance body rotating in a jet parallel to the jet axis leaves a spiral wake behind, out of which, after complete velocity exchange with the surrounding flow, a rotation of the jet is formed. Properly applied, this idea can be used to produce rotating air jets. In the present case, the following factors must be kept in mind:

1) The drag must be evenly distributed over the whole jet section to prevent disturbance of the axial velocity distribution,

2) The said drag distribution must remain uniform even with rotation about the jet axis,

3) The arrangement must assure that the velocity exchange of the wake with the surrounding flow takes place as soon as possible and that the turbulence caused by the drag is changed to heat as quickly as possible.

The first condition is met by any screen covering the jet section, condition 2 requires a screen of round wires, since the circular cylinder alone has constant drag unaffected by the angle of attack; condition 3 demands the finest possible drag distribution, that is, the thinnest wires consistent with adequate strength.

The experimental set-up is shown in figure 1. A set of four screens is mounted in series in a guide ring supported from the outside and actuated by an electric motor.

The rotation of this screen about the jet axis gives the jet its rotation. This rotation was verified by measuring the radial course of the angle between jet axis and resultant flow direction. The tangent to this angle gives the ratio of tip to axial speed. It was measured with tufts sighted through a telescope. The measuring accuracy amounted to ±0.5°. While developing the test arrangement a test was made with a single screen, the result of which is given in figure 2. There is quite some jet rotation, although the rise of the angle is rather too great outwardly and in nowise linear. The unsatisfactory flow direction is caused by the effect of the centrifugal force.

Computing the pressure rise produced radially by the centrifugal force of a rotating jet we find

$$P_z = \rho \left(\frac{U}{R}\right)^2 \int_0^r r dr = \frac{\rho}{2} \left(\frac{U}{R}\right)^2 r^2$$

where

U is tip speed at jet boundary,

R, half the jet diameter,

ρ, air density,

r, varying distance from jet axis.

This pressure rise is superposed on the pressure jump in the plane of the screen and results in the axial speed being greater in the jet core than at the outer circumference. The enhanced flow through the screen in the jet center reduces the angles measured at this point and so explains the angle curve in figure 2.

To remedy this defect the reaction of the centrifugal pressure on the flow through the screen must be made small. For this reason, several layers of screens were resorted to and the pressure jump increased. The corresponding tests showed that four screens are needed in order to produce a suitably rotating jet (fig. 3).

As the number of screens is increased, the energy input necessary to push the air stream through them increases also; hence it was logical to mount the screen at a point of slower speed, in the wind tunnel in the dead-air space ahead of the nozzle. But the following consideration militates against mounting it at that point.

On contraction of a rotating jet the tip speed becomes proportional to the radius which increases the axial velocity inversely proportional to the area. For the normal contraction of area of 1:4 in wind tunnels, the ratio U/v is accordingly cut in half by the nozzle. Now the test has shown that the ratio U/v downstream from a rotating screen cannot be raised arbitrarily, but rather that a ratio of $\frac{U}{v} = 1.6$ presents the maximum obtainable value. Any further increase in screen rotation produces a sudden reversal of flow form with nonrotational return flow in the center and high positive speed with marked positive rotation on the outside. The screen then operates somewhat like a centrifugal blower.

The second flow form is, of course, unsuitable for spinning measurements, hence the value $\frac{U}{v} = 1.6$ should not be exceeded. This maximum is necessary for spinning investigations so that the screen must be mounted in the nozzle orifice, despite the greater energy loss. It is only in cases where this ratio $\frac{U}{v} = 1.6$ is intentionally foregone and about half is deemed sufficient, that the much simpler and less energy-consuming installation behind the honeycomb may be essayed.

The first tests were made with rotating open jet. But it was found that the rotating free jet disintegrates under load through a fixed airfoil model and that the rolling moments of the wing are markedly lower than those for rotating wing and fixed jet.

This was overcome with a cylindrical supplementary nozzle which surrounds the jet for about 200 mm behind the model wing. The suspension wires for the wing were carried through slots in the supplementary nozzle (fig. 10).

IV. TEST PROCEDURE

The experimental test of the method was made with an arrangement permitting the rotation of either model or jet. The model rested on a long shaft with electric motor at the rear end (fig. 4). The motor served both as drive and brake. For the determination of the moment transmitted to the wing, the casing of the motor was pivoted and connected by a wire with a scale. An interruptor disk on the motor axle recorded the revolutions by electric timer and stop watch.

The peripheral speed of the jet was measured with a light wind vane (fig. 4) carried along by the jet without slip (fig. 10). Every rotation closed a small electric contact so that the revolutions could be recorded by electric timer and stop watch (as on the motor). The axial velocity was recorded with Prandtl tube and micromanometer.

The wing was either measured in the spinning range through the air forces or in the unstalled flow range driven by motor and the respective autorotation and damping moment measured on the balance. This moment was occasionally held constant for a test series and the wing rotation progressively replaced by jet rotation. It was found that the rotations of the wing decreased exactly by the amount of jet rotations, until finally the wing came to rest, when the jet rotations reached the initial rotations of the wing for static jet. Figures 5 to 8 illustrate the results, the abscissas denoting the jet rotations and the ordinates the wing rotations. It is readily seen how for different angles of attack and autorotation or damping moments the rotation of the model can be replaced by the corresponding rotation of the jet. Disregarding minor discrepancies probably due to imperfections of the first attempts, the practicability of the method has been proved by the tests.

On conclusion of the experiments we measured the rolling and damping moments on an M 5 airfoil section at 10, 20, and 30 degrees angle of attack for different rates of roll. First, came the measurements on the rotating wing with the aid of the above described electrical rotation device. Two sets of measurements were taken; one in the calm stream with the screen necessary for the jet rotation, the other without screens. Then the same measurements were repeated in the rotating jet; the model being suspended from the six-component balance (figs. 9 and 10). Figure 11 shows the recorded moments about the jet axis against the ratio U/v at the wing tip for all three arrangements. The curves for the rotating jet reach only as far as $\frac{U}{v} = 0.3$, since technical defects of the original version prohibited higher tip speeds of the screens. Figure 11 discloses the following: for $\alpha = 10^\circ$, that is, for unstalled flow over the whole wing in the low U/v range, the measurements on the rotating wing with screen coincide with those for the rotating jet and fixed wing. The same holds true for the measurements with completely separated flow at $\alpha = 30^\circ$, against minor discrepancies for the ranges of partial separation of flow ($\alpha = 20^\circ$ and $\alpha = 10^\circ$, respectively). Inasmuch as it is common knowledge that, in the range of incipient separation, the reproduction of the test values is accompanied by scattering even if the test method is not changed, the agreement of both test methods must be proncunced good.

The jet rotation method makes investigations possible which were heretofore very difficult; first among these is the measurement of the yawing and pitching moments, which with rotating jet can be read on the normal 6-component balance along with the other quantities, whereas, even on the very latest rotating spinning balances, these components must be measured separately and with the most careful balancing of all parts.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

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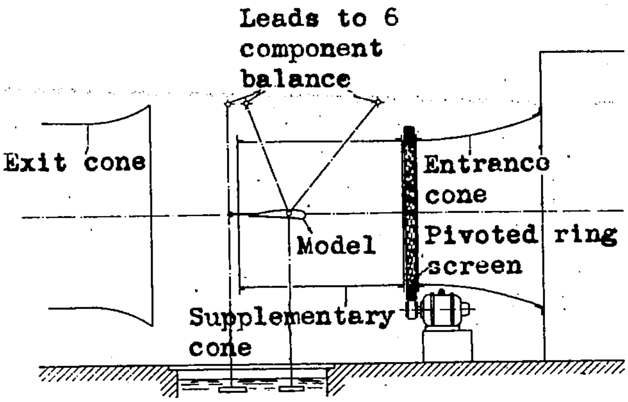

Figure 1.- Spinning test setup in the 1.2 m wind tunnel schematical plan.

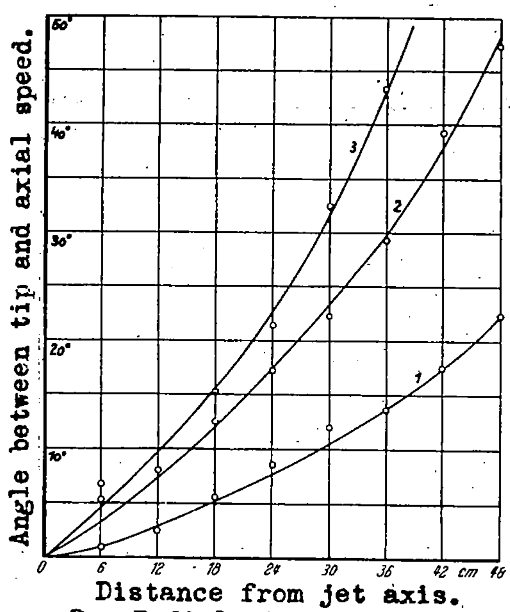

Figure 2.- Radial tip speed distribution with a screen having 40 percent solidity for three different screen speeds.

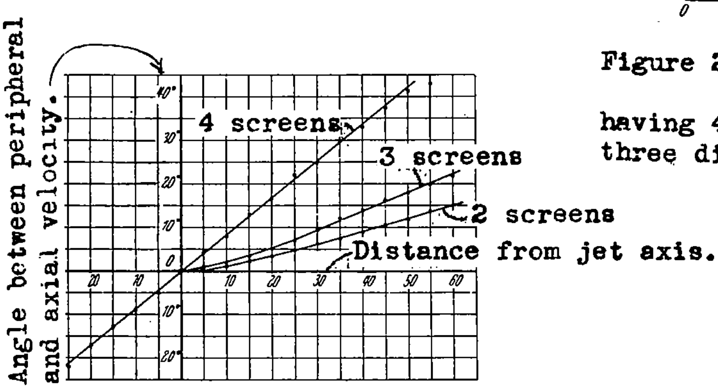

Figure 3.- Radial tip speed distribution for different screen speeds.

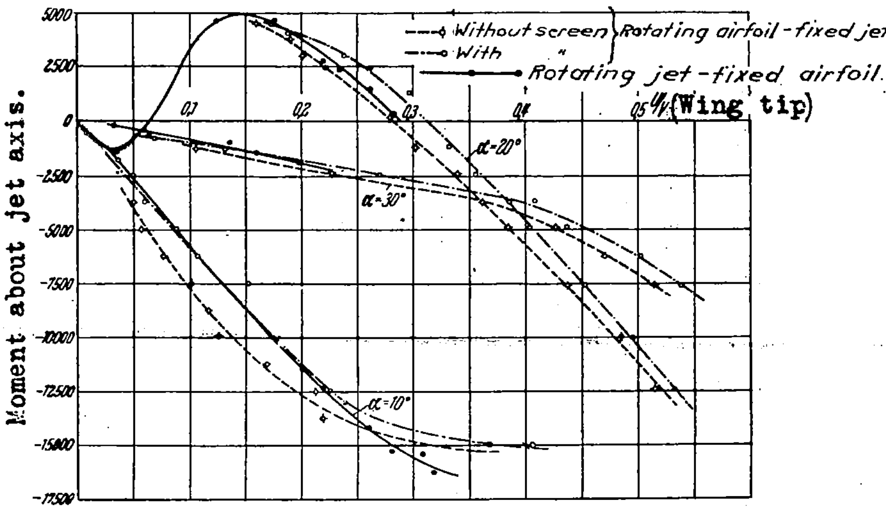

Figure 11.- Spinning moments of airfoil section M5.

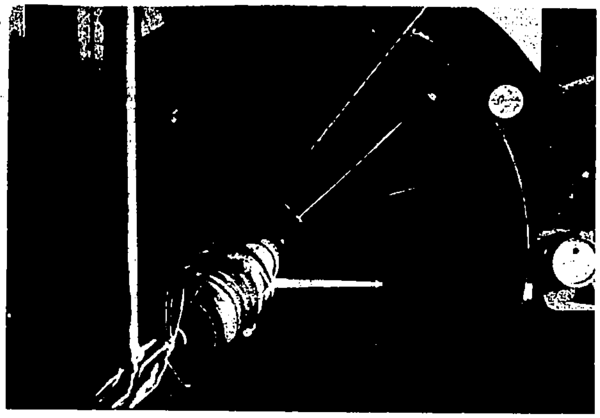

Figure 4.- Model airfoil mounted on rotation device.

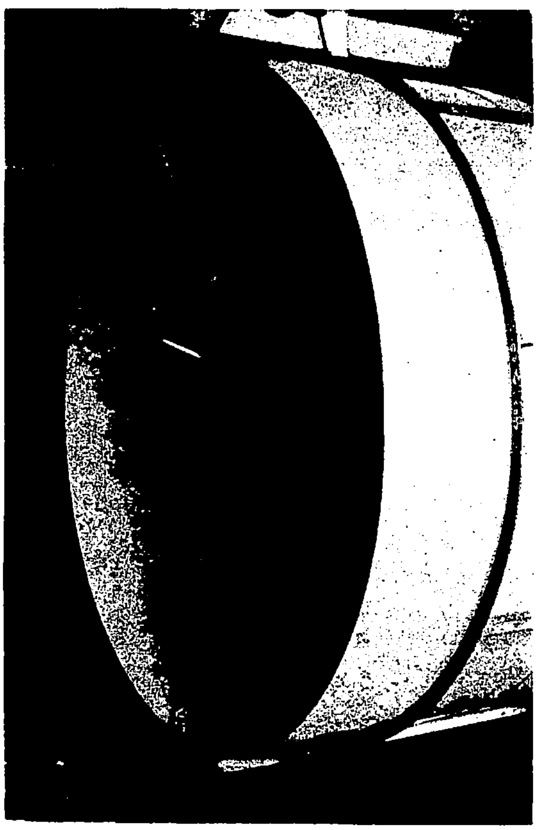

Fig.9- Side view.

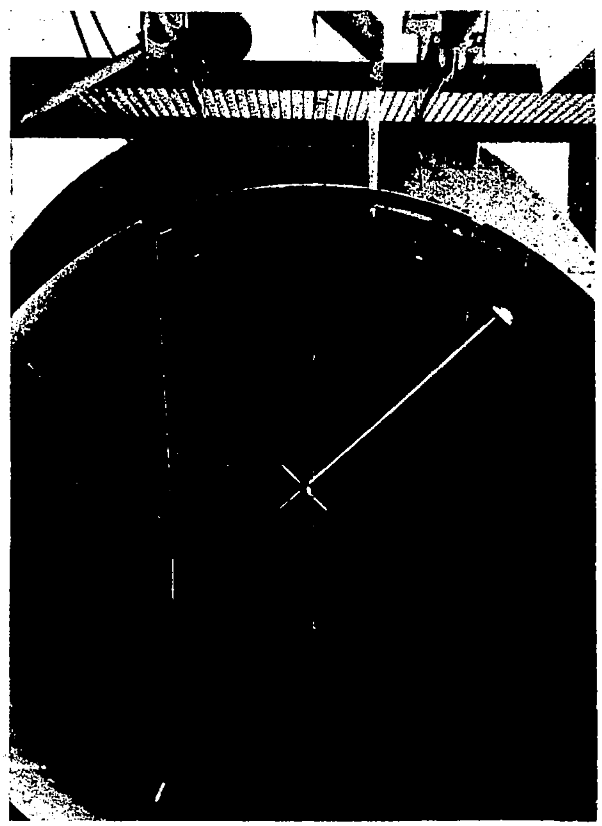

Fig.10- Front view.

Figure 9,10.- Side and front view of airfoil and six component balance.

$M = 0;\ \alpha = 20^\circ$

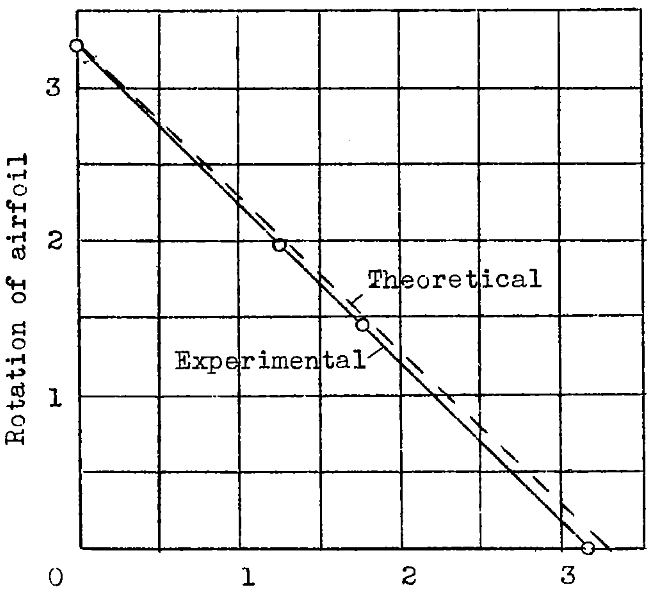

Figure 5.

$M = 0;\ \alpha = 25^\circ$

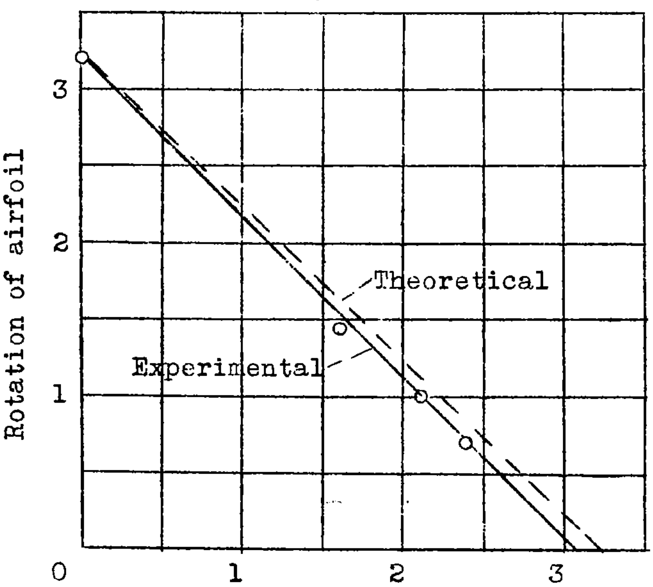

Figure 6.

Figures 5,6.- Jet rotation substituted for airfoil rotation.

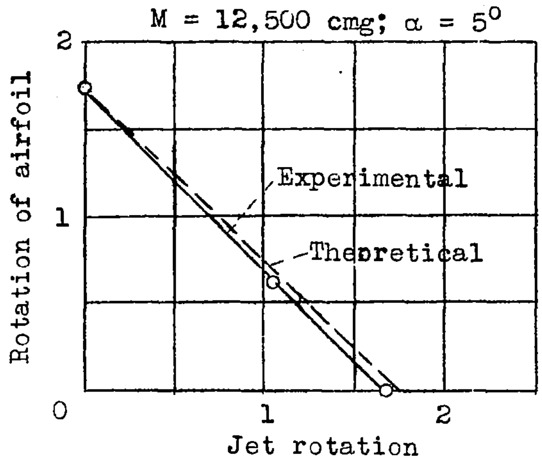

Figure 7.

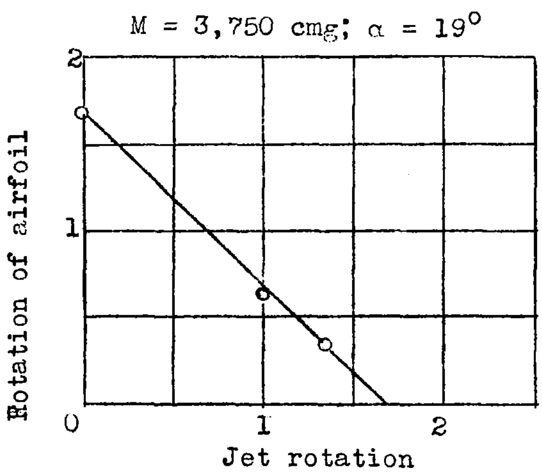

Figure 8.

Figures 7,8.- Jet rotation substituted for airfoil rotation.